THE FORGOTTEN NAUTICAL ASTRONOMICAL INSTRUMENTS

Fabrizio Benincasa, Matteo De Vincenzi, Gianni Fasano
CNR Institute of BioEconomy via Madonna del Piano 10 Sesto Fiorentino (Florence, Italy)
phone +39 055 5226058; e-mail fabrizio.benincasa@ibe.cnr.it

Abstract – Astrology and meteorology have always had great importance for agriculture and navigation. This paper describes some measuring and forecasting instruments which, at their design epoch, had a moderate success in sailing a small sea like the Mediterranean, but then over time they were forgotten because they were supplanted by other more reliable instruments even in the largest seas. In particular, we refer to the instruments for astrology, starting with a device, the *parapegma*, made when meteorology was still a particular aspect of astrology. The second instrument is a calculator for determining the position of the stars; so some instruments are then described to establish, for example, the position of a ship with respect to the Sun or the North Pole, and others to determine direction and speed of ship.
The short list ends with a return to meteorology with two storm forecasters, essential for quite sailing which, unfortunately, never worked as their inventors hoped.

1. Introduction

The connection between astronomy and meteorology started long time ago and remained stable for a long period. The Alexandrian astronomer Claudius Ptolemy (circa 100 - circa 175) in his work, *Phaseis - Phases of the fixed stars and their data collection*[1] [11] included a meteorological calendar, a list of dates of regular seasonal climate changes, first and last apparitions of stars or constellations, at sunrise and sunset, and solar events such as the solstices; all information organized according to the solar year. Ptolemy believed that astronomical phenomena caused the seasonal changes of the weather; he attributed the lack of perfect correlation between these events to the physical influences of other celestial bodies; for the astronomer, the weather forecasting was a particular aspect of astrology.

These aspects had a practical purpose relating to both agriculture and navigation. In this work we refer more to this latter aspect; in fact, we propose some forgotten forecasting and measurement instruments, starting with a device (*parapegma*) that shows how ancient meteorology was within a cultural framework of astrological type. More markedly astronomy-oriented instruments are then shown, which were fundamental for navigating the "small" Mediterranean and, subsequently, they were used to get out and start the great ocean crossings. It will therefore be no surprising to note that the most ancient instruments were conceived and carried out in Mediterranean regions, where they were found, even in their most archaic forms.

From the instruments reported here, in chronological order, we give a description of their functions; for the methods of operation and use, we refer to the, unfortunately, quantitatively modest bibliography.

---

[1] Only the second book of the work has survived [1001].

Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Fabrizio Benincasa, Matteo De Vincenzi, Gianni Fasano, *The forgotten nautical astronomical instruments,* pp. 390-400 10.36253/979-12-215-0030-1.35

2. The instruments in chronological order

2.1 Parapegma (5th century BC)

The Greeks had no meteorological instruments to confirm or deny their insights regarding the weather, which was related as a rule to astronomical events. For this purpose, public almanacs were placed in many squares in Mediterranean cities, called *parapegmata* (plural of *parapegma* from the Greek verb *parapegma* to fix into), which indicated the position of the stars and the weather in the local area, sometimes with the addition of rudimentary forecasts. For example: *"the shoulders of the Virgo* [constellation] *are rising"*, *"Rising of Arcturus* [of the constellation Boötes]*: south wind, rain and thunder", and "the weather will likely change"* ([6] p.32). The first versions of parapegma were carved on stone; next to the descriptions of the events there were holes in which pegs were inserted to identify the day, the month, etc., fig. 1.

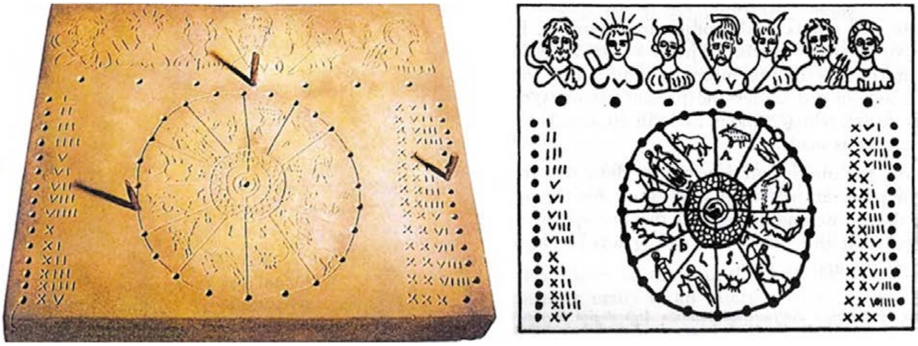

Figure 1 – On left: modern reconstruction of the parapegma found in the *Terme di Traiano* (Rome) at the beginning of the nineteenth century [9]. On right: reproduction of the drawing traced on the *parapegma*; above, from left to right, the days of the week dedicated to: Saturn, Sun, Moon, Mars, Mercury, Jupiter, Venus; the zodiac signs in the circle, Aries at the top right, indicated by "A", and the other zodiac signs proceeding counterclockwise, on the sides the days of the month.

2.2 Antikythera calculator (1st century BC)

In 1902 in the north-west of Crete, in a wreck in the depths of the Antikythera island, a mechanical device was found. It was indefinable because covered with encrustations; on the mechanism some engravings were glimpsed that referred to astronomical events dating back to 77 BC. The first rigorous studies on this strange mechanism were carried out in 1951, but only in the 1970s it was possible to understand, at least in part, its functioning.

After a thorough cleaning of the encrustations, some inscriptions could be deciphered that bear the words: *76 years*, *19 years*.

The first number recalls the Greek astronomer Callippus of Cyzicus (Asia minor 4th century BC), a pupil of Eudoxus and he worked with Aristotle at the Lyceum, known for having completed the geocentric theory and for having established a period (*Callippic cycle*) of *76 solar years*. This period is useful for the determination of eclipses and corresponds to four times the *cycle of Meton*[2], which is 19 years; this cycle is a period after which the phenomena related to the Sun and the Moon are repeated in the same order, in the same months and roughly the same days.

In the line below the one in which there are the above-mentioned numbers, there is the number *223* which most likely refers to the cycle of eclipses. They occur, with a good approximation, according to a cycle, called *saros* (Chaldean word, first millennium BC), which is repeated every *223* synodic lunar *months*, and since these are 29,53059 days, the cycle lasts 6585,32 days (i.e., 18 years, 11 days, 8 hours). After this time interval, the Sun, Earth, and Moon find themselves in almost the same positions assumed in the previous cycle and therefore the eclipses are repeated with the same sequence. After this time interval, the Sun, Earth, and Moon assume almost the same positions of the previous cycle and therefore the eclipses are repeated with the same sequence.

The X-ray investigations allowed to explore the interior of the limestone block. This made possible to understand that it was a complex mechanical machine that allow to predict the position of celestial bodies, the dates and times of eclipses, the lunar phases, etc. The most recent studies, carried out with computed tomography and high-resolution digital processing of the exposed surfaces, have been able to show previously neglected details and decipher previously undetected inscriptions. The positions of the Sun and the Moon on the Zodiac traced on one of the two quadrants, with which the device is equipped, were more evident; moreover, it was clarified how it was possible to predict the eclipses of the Sun and the Moon. Other previously undetected inscriptions have suggested that the mechanism was also able to predict the movements of the planets, figure 2. [12] [13] [15] [1007].

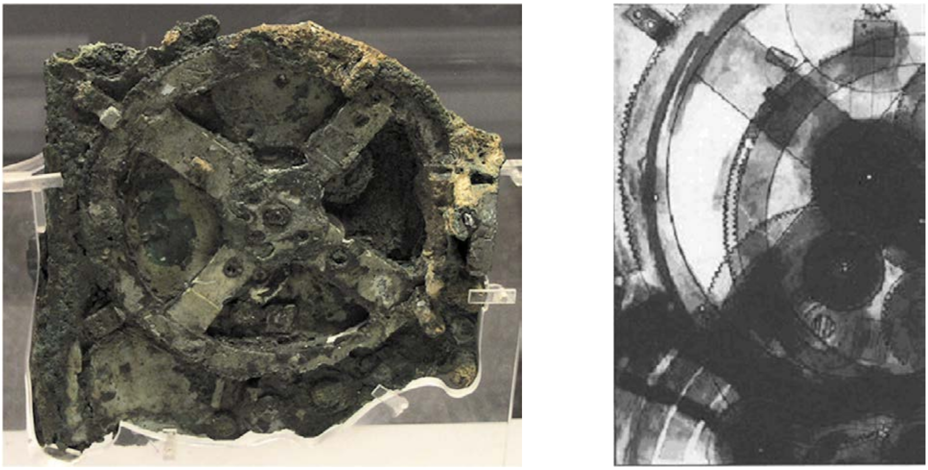

Figure 2 – On left: Antikythera mechanism, preserved at the National Archaeological Museum of Athens. The mechanism consists of a complex system of 30 wheels and plates with engravings relating to zodiac signs, months, eclipses [1008]. On right: an image obtained by computerized axial tomography of the artefact [1007].

---

[2] Meton of Athens was a Greek astronomer of the 5th century BC.

2.3 Astrolabe (2nd century AD)

Astrolabe, from the Greek *astrolabon* lit. “which takes the stars”, is an instrument that allows to measure the (angular) height of the Moon, the Sun, and other celestial bodies, without using mathematical formulas. The astrolabe also permits to determine the hours of the day and night, to draw horoscopes, to establish the height of the mountains, etc. The theory on which the astrolabe (about 150 BC) is based can be traced back to the Greek astronomer Hipparchus of Nicaea (194 BC - 120 BC); but only Claudius Ptolemy, author of the *Planisphaerium*, the oldest treatise on the subject, gives some certainty about his knowledge of the astrolabe. However, the oldest existing astrolabes are from the 9th - 10th centuries, while from the previous period there are only attestations by Greek and Syriac authors who describe their functioning and evolution. In the Middle Ages the astrolabe was perfected by the Arabs who introduced it to Europe through Spain. For further information, see [1], [8], [17].

Figure 3 shows an astrolabe in gilt brass (diameter 165 mm), of Arab workmanship; the astronomical data reported on the tool indicate that it was made to operate at latitudes between 30° and 40° and suggest that the construction is prior AD 1000; according to tradition the instrument would date back to the time of Charlemagne (9th century).

Figure 3 – Astrolabe in gilt brass, of Arab workmanship, with case. Reproduction by permission of *Museo Galileo*, Firenze – Photo by Franca Principe.

2.4 Nocturnal or nocturlabe (possibly 13th century)

The *nocturnal*, or *nocturlabe*, is a sort of astrolabe for the night sky, showing the positions of some brilliant circumpolar stars, such as those of the constellation *Ursa Major*, with respect to the *Pole Star*. Some authors attribute the invention of the nocturnal to the Spanish astrologer, from Palma de Mallorca, Ramon Llull (1232 - 1316), but others report citations relating to this type of instrument in much earlier periods. [4] [1009]. Although it is unknown when the first versions of the nocturnal were made, it is known that it was used, in limited way, until the 18th century.

2.5 Jacob's staff or *Baculo mensorio* (13th-14th century)

Jacob's staff or *cross-staff*, also known in Italian as *Baculo mensorio*, was able to measure an amplitude or angular opening, with respect to a predetermined point, for example of two stars, or the extremes of a tower or mast of a ship. The first descriptions of this instrument have been attributed to the rabbi and mathematician Levi ben Gershon (1288 - 1344), who lived in Provence (Southern France). In its simplest configuration, the instrument consisted of two wooden rods, one shorter, mounted transversely to the other and could slide over it. Figure 4 shows Jacob's Staff and an illustration explaining its use. On the long rod some subdivision notches were engraved which were used to identify, on it, the position of the sliding rod. For measuring the angular distance between two fixed points, the extreme marked of the long rod approached the eye and the short rod was sliding until its extreme points overlapped the two fixed points. The illustration in Figure 4 shows an operator measuring the height of the Sun on the sea horizon.

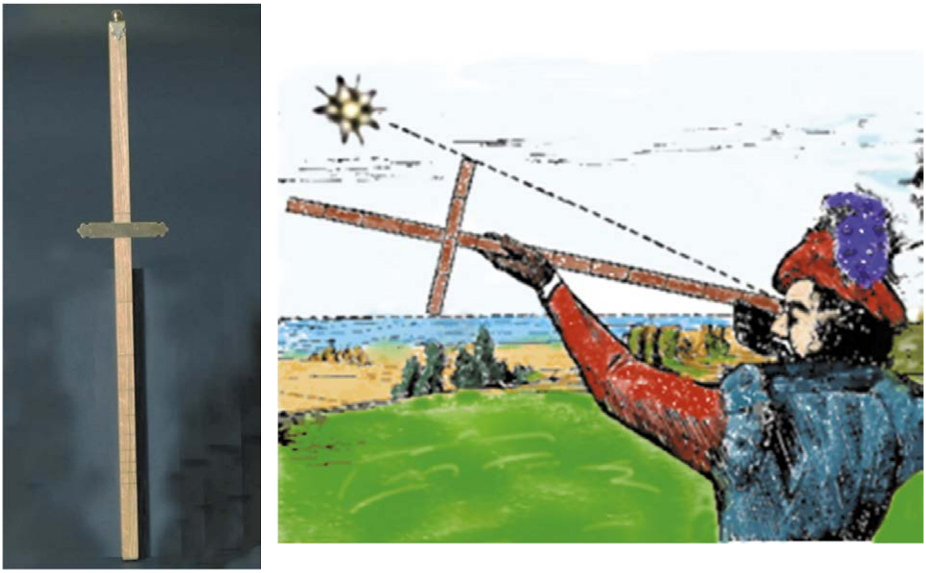

Figure 4 – Jacob's staff (on left); an operator measures the height of the Sun on sea horizon (on right) [1002].

In seafaring practice, the joint use of Jacob's staff and compass was helpful for quick, even if rough, bearings. In astronomical practice, under more controlled measurement conditions, the instrument was used to study the motion of the stars and to compute the Ephemerides. This instrument was widely used in Europe throughout the Middle Ages; between the 15th and 16th centuries, its construction and use were described in numerous treatises. With the 17th century the staff was replaced by the *quadrant* which in turn was abandoned in the 18th century, with the adoption of the *octant*.

2.6 Nautical or sea astrolabe or mariner's astrolabe (16th century)

In the 16th century, a Spanish-Portuguese reinterpretation of the astrolabe (previously described) made it particularly useful in the seafaring, for the detection of the height of the Sun and the Pole Star. Figure 5 shows the instrument and an illustration explaining its use to detect the angular height of a star. The frame of the sea astrolabe was heavy and widely holed to facilitate observation in adverse weather conditions: the weight kept the instrument on the vertical, despite the pitch and roll of the ship; the holed frame prevented the instrument, with strong winds, from behaving like a sail and swinging in the observer's hands. Despite these precautions, the absolute immobility and verticality of the instrument, during the measurement, could only be guaranteed on land. From the 16th century the astrolabe became a fundamental instrument for navigation and remained in use until the 18th century when it was replaced by a new instrument, first the octant and later the sextant.

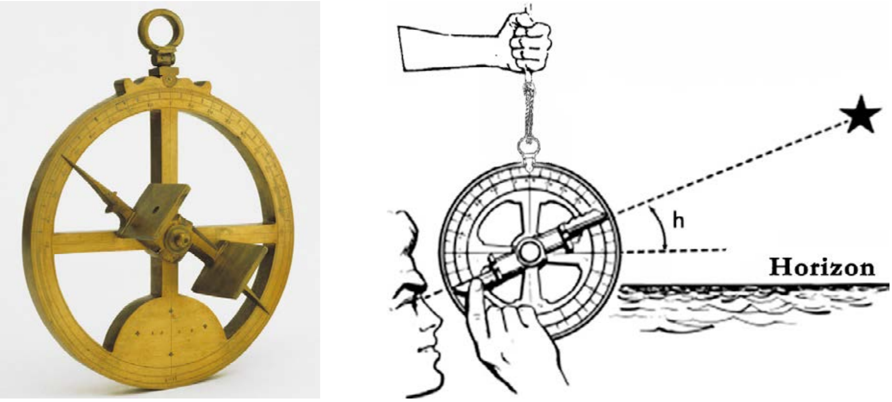

Figure 5 – Nautical astrolabe by Francisco de Goes, 1608, and its use [1003]. Medici collections (Robert Dudley bequest), *Museo Galileo* (inv. 1119), Firenze. Image reproduction by permission of *Museo Galileo,* Firenze – Photo by Franca Principe.

2.7 Ship log or chip log (16th century)

Until the 16th century, the measurement of the speed of a boat could not be performed reliably because there were no fixed references in open sea. […] *Experienced pilots could make reasonably good guesses at how fast they were going by spitting in the water and timing (by saying Hail Marys) how quickly the spittle was carried away, but that* *was obviously not a high-precision method* [...] [2] pp.228-229. For this purpose, in the sixteenth century, a weighted triangular wooden tablet began to be used, a chip log figure 6, fixed with a long line to a roller placed on the stern. The tablet was thrown into the sea, in the time of 30 seconds (1/120 of an hour), detected through a sandglass, it was measured how much line the tablet had dragged into the sea; this provided the length of the distance traveled by the ship in that time interval. Length of the distance traveled, and time taken provided an estimate of the ship speed. For an immediate indication of the speed, on the line were knotted, at regular intervals, some little cables, then counting how many of these knots were seen going down into the water in the 30 seconds. The number of knots went down into the water, in 30 seconds, provided the speed of ship, expressed in knots over the time indicateted. Obviously, the obtained measurement (being conditioned by currents, wind, etc.) was different from the one that would have been detected with reference to the seabed.

In her book *Longitude* [14], pp. 13-14, Dava Sobel, an American science popularizer and science reporter, states on the use of the ship log: […] *The captain would throw a log overboard and observe how quickly the ship receded from this temporary guidepost. He noted the crude speedometer reading in his ship's logbook, along with the direction of travel, which he took from the stars or a compass, and the length of time on a particular course, counted with a sandglass or a pocket watch. Factoring in the effects of ocean currents, fickle winds, and errors in judgment, he then determined his longitude. He routinely missed his mark, of course searching in vain for the island where he had hoped to find fresh water, or even the continent that was his destination. Too often, the technique of dead reckoning marked him for a dead man* [...].

Figure 6 – Ship log and sandglass to estimate the relative speed of the ship [1004].

2.8 Davis Quadrant (16th century)

The Davis quadrant originates from the Staff of Jacob; in the two hundred years in which it was used on ships all over the world, the quadrant underwent a notable evolution from its first elementary form. The instrument allowed to detect the height of the Sun without having to observe the star continuously and directly, with the danger of ruining of the view, as often happened to sailors. Perhaps the first quadrant was made by Thomas Harriot [16]. The most famous, however, is the quadrant of Captain John Davis (1550-1605) who described the first two versions of his instrument in a book of 1594, "*The Seaman's Secrets*" [1005]. However, we want to underline that Davis was neither the first nor the last to design quadrants, but he was the one who managed to establish himself, in the history of navigation instruments, also thanks to other manufacturers who, over time, have essentially improved his prototypes. [10].

The third, more complex version, was made by an anonymous manufacturer in the mid-seventeenth century and constitutes the instrument that today we identify as the *Davis Quadrant* which operated on a quarter of a circumference (hence the name of the *quadrant*). Figure 7 shows the third version of the quadrant and an illustration explaining its use.

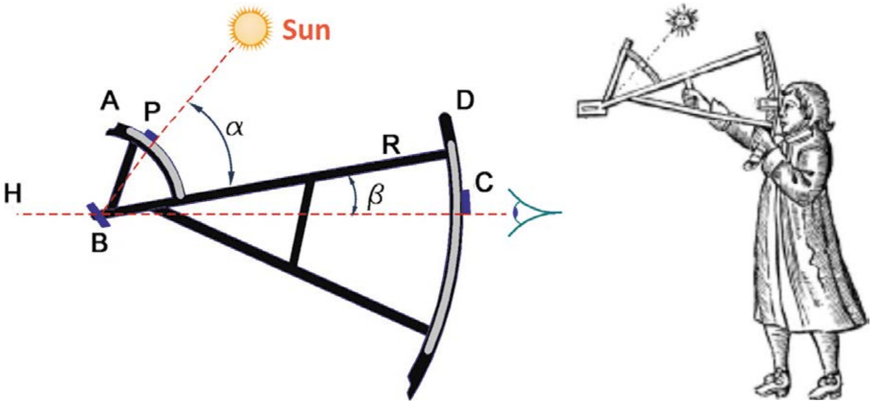

Figure 7 – Third version of Davis quadrant and an illustration, from [7], explaining its use.
A: 60° graduated arc bracket on which P flows. **B:** sight of horizon. **C:** ocular.
D: graduated arc bracket on which C flows. **H:** horizon. **P** shadow fin.
R: ruler. $\boldsymbol{\alpha} + \boldsymbol{\beta} = h$: elevation of Sun.

2.9 Octant (18th century)

The measurement of the altitude of the Sun or other celestial bodies on the horizon, or the angular distance between them in relation to an observation point, especially during navigation, was not effectively resolved either with the astrolabe or with the instruments that followed, from the primitive Jacob Staff of to the more sophisticated Quadrants of the seventeenth century. Only in the 18th century navigators began use of the *Octant*, an instrument so called due to its shape: a circular sector with an arc of one eighth of circumference. The instrument, used together with the Ephemeris and a clock, allowed to determine, with sufficient precision, one's position on the nautical chart, when the sea was not too rough. Several people, independently of each other, brought innovations to the octant, such as in 1731 the English mathematician John Hadley (1682 - 1744) and in 1732 the French mathematician and astronomer Jean Paul Fouchy (1707 - 1788). In its latest version the instrument was equipped with a double reflection mirror system that made the image of the celestial body observed considerably more stable on the horizon; with an only flaw: the device could not measure angles greater than 90°. This limitation was overcome at the end of the 18th century when a similar instrument was made but on an arc of one sixth of a circumference, called the *Sextant*. The two-mirror system, while maintaining the accuracy of the octant, has expanded the possibility of measuring angles up to 120°; the latter instruments, albeit in much more complex forms, are still used today.

2.10 Storm indicators (19th century)

During navigation it was important always know direction and speed of the ship, but was it also needed to forecast the arrival of storms. This quick excursus on forgotten navigation instruments ends by citing two versions of *storm indicators*, or meteorological instruments, as is the first instrument with which this work begins.

The first instrument, called *Stormglass*, was built in the second half of the 18th century and perfected in the mid-19th century by Admiral Robert FitzRoy (1805 - 1865). The Stormglass consisted of a sealed glass cylinder containing a mixture based on distilled water, ethanol, camphor, ammonium chloride and potassium nitrate. The liquid was clear at high temperatures, but, according to the Admiral, as the temperature and pressure changed, the clearness decreased due to the formation of saline crystals of various shapes and sizes inside the cylinder [1006]:

- If the liquid in the *Stormglass* is clear, the weather will be clear and bright.
- If the liquid is turbid, the weather will be cloudy and possibly with precipitation.
- If there are little dots in the liquid, the weather will be humid or foggy.
- If there are small crystals in the liquid, thunderstorms can be expected.
- If the liquid contains small crystals on sunny winter days, snow is coming.
- If there are large crystals in the liquid, the weather will be cloudy in temperate zones or snowy in winter.
- If there are crystals in the liquid at the bottom of glass, this will indicate frost in the winter.
- If there are filaments in the liquid at the top of glass, it will be windy.

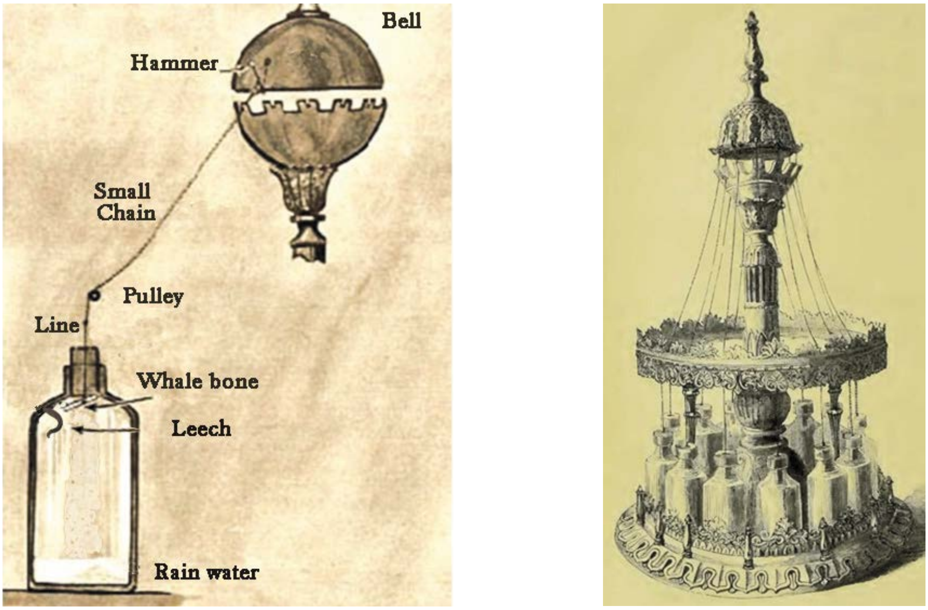

Figure 8 – *Tempest prognosticator* or *leech barometer*. On left, the operating principle is shown; on right, the realization presented in the First Great Universal Exhibition of 1851 in London. This device never found a practical application.

The second storm indicator, called also *tempest prognosticator* or *leech barometer* (figure 8) since the main component was this small animal, was made by the English surgeon George Merryweather (1794 - 1870). He was convinced that medicinal leeches were able to forecast the weather, given that they were agitated when a storm came. In Italy the instrument was known as *Bdelleudiometro* from the Greek *bdelle* = leech, *éudios* = good, in reference to weather, and *métron* = measure [3]. Using this "effect", Merryweather invented a device comprising of a dozen glass bottles, containing rainwater, in each of which a leech was placed. Each bottle was topped with a tube containing a piece of whalebone wire connected to a small hammer that would strike a bell when the leech attempted to get out of the tube. The greater the number of leeches ringing the bell, the greater the likelihood of a storm approaching [5].

The first of the two instruments, *Stormglass,* was more successful as the English Crown, following the violent storm that sank the Royal Chater ship with its 370 passengers, distributed stormglasses to many small fishing communities for consultation before setting sail from their ports. However, it was an ephemeral success since its real validity was never confirmed by practical application.

3. Conclusions

In the selection of the instruments, we mainly referred to the Mediterranean regions which are perhaps the most studied in the world, from a prehistoric and historical point of view. This contribution intends to underline that in this context, together with the *Great History* of men and events that determined the birth and development of civilizations, there is also a *lesser-known history* of forgotten things, in our case of instruments for forecasting and measure, some absurd, others more rational, which, however, are the basis of today's instruments.

We say nothing new by stating that *ex nihilo nihil fit,* nothing comes from nothing, and if today we have an electronic technology that can everything, this is the daughter of humble technology made with stones and wood. It is only by remembering the modest origins of the parents that one can appreciate, in the right measure, the sensational successes of the children.

4. References

[1] A. Bausani (1977) - *Appunti di astronomia e astrologia arabo-islamiche*, Cooperativa Libraria Universitaria Editrice Cafoscarina, Venezia

[2] C. D. Conner (2005) - *A People's History of Science: Miners, Midwives, and Low Mechanicks*, Nation Books, New York

[3] A. De Carli (1795) – *Del Bdelleudiometro ossia osservazioni meteorologiche fatte a Milano colle mignatte*, in "Opuscoli scelti sulle scienze e sulle arti tratti dagli Atti delle Accademie, e dalle altre Collezioni filosofiche, e letterarie, e dalle opere più recenti inglesi, tedesche, francesi, latine, e italiane, e da manoscritti originali, e inediti", Tomo XVIII, G. Marelli, Milano pp. 204-213

[4] E. Farré i Olivé (1996) - *La Sphaera Horarum Noctis de Ramon Llull*, La Busca de Paper n. 22, Primavera, pp. 3-12 www.eduardfarre.com/pdf/EFarre_RamonLlull.pdf

[5] J. Foer, D. Thuras, E. Morton (2017) - *Atlas Obscura. Guida alle meraviglie nascoste del mondo*, Mondadori, Milano.

[6] R. Hamblyn (2001) – *The invention of clouds: how an amateur meteorologist forged the language of the skies.* Farrar, Straus and Giroux, New York

[7] N. de Hilster (2011) - *The Early Development of the Davis Quadrant*, Bulletin of the Scientific Instrument Society, No. 110, pp. 14-22. www.dehilster.info/docs/SIS_bulletin_110_Hilster_Davis-Quadrant_2011.pdf

[8] D.A. King (1987) - *Islamic Astronomical Instruments*, Variorum Reprints, London

[9] D. Lehoux (2007) - *Astronomy, Weather, and Calendars in the Ancient World. Parapegmata and Related Texts in Classical and Near-Eastern Societies*. Cambridge University Press, Cambridge

[10] W. E. May (1973) - *A History of Marine Navigation*, G. T. Foulis & Co. Ltd., Henley-on-Thames, Oxfordshire, ISBN 0-85429-143-1

[11] M. G. Nickiforov (2014) - *Analysis of the calendar C. Ptolemy "Phases of the fixed stars"*, Bulgarian Astronomical Journal Vol. 20, pp. 68-85 https://astro.bas.bg/AIJ/issues/n20/MNikifor.pdf

[12] G. Pastore (2010) - *Antikythera Calculator advances modern science of 19 centuries*, Adv. in Space Research, Vol. 46, Issue 4, pp. 552-556, doi:10.1016/j.asr.2010.04.002

[13] D. J. Price (1974) - *Gears from the Greeks. The Antikythera Mechanism: A Calendar Computer from ca. 80 B. C.* Transactions of the American Philosophical Society. New Series. 64 (7), pp. 1-70, doi: 10.2307/1006146

[14] D. Sobel (2005) - *Longitude: the true story of a lone genius who solved the greatest scientific problem of his time*, MJF Books, New York

[15] D. Spinellis, (2008) - *The Antikythera Mechanism: A Computer Science Perspective*, Computer, vol. 41, no. 5, pp. 22-27, doi: 10.1109/MC.2008.166

[16] E. G. R. Taylor (1953)- *I-Thomas Hariot's Manuscript*, Journal of Navigation, Vol. 6 (2), pp.131-140, doi: 10.1017/S0373463300035438

[17] P. Trento (2011) - *L' astrolabio. Storia, funzioni, costruzione*, Stampa Alternativa, Roma www.tecalibri.info/T/TRENTO-P_astrolabio.htm

4.1 Sitography

[1001] http://www.poesialatina.it/_ns/Greek/testi/Claudius_Ptolemaeus/Phaseis.html (17/05/2022)

[1002] http://www.igmi.org/museo/strumento.php?sender=catalogo&id=324 (23/02/22)

[1003] https://it.wikipedia.org/wiki/File:Astrolabe_(PSF).png 🅮 (30/04/22) Author P. S. Foresman

[1004] http://www.museodelmaredinapoli.it/ToposCronosNautes/Solcometro%20a%20barchetta.htm (24/02/2022)

[1005] http://www.stexboat.com/books/seasecr/dseasec1.htm (24/02/2022)

[1006] https://web.archive.org/web/20150120114915/http://www.weathernotebook.org/transcripts/2004/05/07.php (30/01/2022)

[1007] http://www.giovannipastore.it/ANTIKYTHERA.htm (28/02/2022)

[1008] https://commons.wikimedia.org/wiki/File:NAMA_Machine_d%27Anticyth%C3%A8re_1.jpg (24/03/2022) GNU Free Documentation License, Author Marsyas

[1009] https://www.uai.it/divulgazione/conoscere/pillole-storia/strumenti/il-notturnale/ (08/04/2022)